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Chromatographic study of the organic matter from Moroccan Rif bituminous rocks



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Moroccan Rif

Abstract The bituminous rocks of the Upper Cretaceous in the Moroccan Rif have been assessed and characterized in detail using organic geochemical techniques and a variety of organic geochemical parameters. The organic matter from 4 sites was studied in order to determine its thermal maturity and its depositional environments. The organic extracts (bitumens) were fractionated on silica-potassium hydroxide column according to the aliphatic hydrocarbons, acid compounds and polar compounds. Aliphatic hydrocarbons were identified by gas chromatography and mass spectrometry (GC/MS).

The distribution of the aliphatic hydrocarbon fractions, and the various organic geochemical parameters (pristane/phytane, isoprenoids/*n*-alkanes, CPI, $C_{27}:C_{28}:C_{29}$ regular, $C_{29}20S/(20S + 20R)$, $C_{29}\beta\beta/(\beta\beta + \alpha\alpha)$, C_{29}/C_{30} hopanes and Ts/Tm) showed that the studied samples were generally mature. Two of the 4 samples appeared to be derived from source rocks deposited under anoxic conditions while suboxic to oxic conditions seemed to have been dominant for the remaining two samples. Rock–Eval pyrolysis data in addition to GC results suggested types II, III and IV kerogens for the studied samples.

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1. Introduction

Morocco is believed to rank seventh in the world for oil shale reserves. Among the three major Moroccan deposits which come up to ground level, Tangier's one (Rif region) which was discovered during the last century is less studied compared to the Timahdit (Middle Atlas) and Tarfaya (South of Morocco) sediments probably due to a lower amount in

bituminous rocks (Nejma, 1989; Halim, 1993; Ambès et al., 1994).

Bituminous rocks are fine-grained sedimentary rocks. Lithologically, bituminous rocks cover a broad range of rocks from shales to marls and carbonates which contain a large portion of the mineral material and a little portion of the organic material (Yen, 1976). The portion of organic material is predominantly kerogen which is an insoluble material in usual organic solvents accompanied by a small fraction called bitumen ($\leq 1\%$ by weight of raw rock), soluble in usual organic solvents (Durand, 1980). This kerogen can yield a significant proportion of an oil of similar appearance to that of crude oil upon non-oxidizing heat treatment (Pyrolysis) (Peters and Cassa, 1994; Hutton, 1987).

In this work a chromatographic study of the organo-soluble fraction (bitumen) was conducted on 4 different samples of Tangier's deposit in order to obtain useful information about the structure and the characteristics of this kind of organic matter (Philp, 1982; Larter and Horsfield, 1993). In addition, the kerogen present in each sample was investigated using the Rock Eval technique.

On the whole, the present study was aimed at obtaining information about the origin and evolution of the organic matter present in the bituminous rocks of the Tangier's deposit and determining the conventional type of each kerogen and their economical potential.

2. Experimental

2.1. Sampling and studied areas

The studied samples of the bituminous rocks are located in four sites from northern Morocco (Fig. 1, Table 1). A sample

of 20 kg was collected from each station (20–80 cm depth). TA, and AA samples are from Upper Cretaceous – bituminous marls and Upper Cretaceous oil shale successively in the unity of the Melloussa–Chouamat (from Massyenne nappe of Flyschs nappes) (Durand-Delga and Olivier, 1988; Saadi et al., 1981; Filatov, 1970) (Fig. 2A). TE, BT samples are from Upper Cretaceous bituminous Phtanites in the unity of Internal Tangier and unity of Ketama – External Tangier successively (from Intrarif of External Rif) (Kornprost et al., 1980; Durand-Delga and Kornprost, 1985) (Fig. 2B and C). The four samples were subsequently crushed, homogenized and sieved to $< 180 \mu\text{m}$.

2.2. Rock-Eval

Bituminous rocks of the studied samples were analyzed using a Rock-Eval 6 Standard device (fully automated) of the Moroccan National Office of Hydrocarbons and Mines in Rabat (Jabobker, 2003, 2004). This technique was developed at the French Petroleum Institute (Espitalié et al., 1977). The crushed sample was pyrolyzed (500–600 °C) under a helium atmosphere with a programmed temperature. The pyrolysis products are quantified according to the temperature.

2.3. Flash pyrolysis (Py-GC/MS)

Flash pyrolysis has been widely used for the analysis of synthetic or natural polymers. Flash analytical pyrolysis was performed using a pyrolyser CDS (Chemical Data System) 5150 Pyroprob. About 4 mg of finely ground crude sample was placed on a $25 \times 1.9 \text{ mm}$ (id) quartz tube filled with quartz wool. The tube was then heated from 350 to 650 °C at

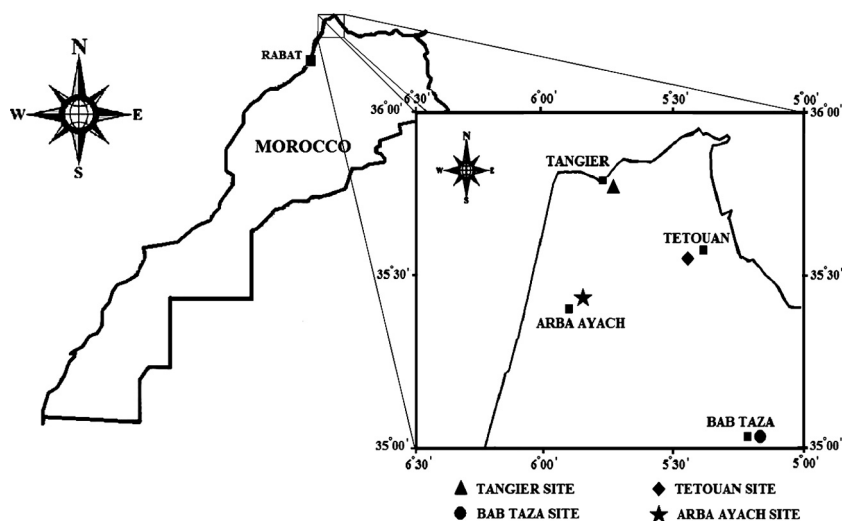


Figure 1 Study area showing the Bituminous rock sampling location.

Table 1 The coordinates of each sampling site of the sediment samples studied.

Site	Symbol of sample	Lithology	Geological age	Longitude (O)	Latitude (N)
Tangier	TA	Marl	Upper Cretaceous	5° 46' 33,23"	35° 45' 38,07"
Tetouan	TE	Phtanite	Upper Cretaceous	5° 27' 32,98"	35° 33' 43,97"
Bab Taza	BT	Phtanite	Upper Cretaceous	5° 10' 51,02"	35° 3' 45,82"
Arba Ayach	AA	Shale	Upper Cretaceous	5° 51' 05,14"	35° 24' 28,54"

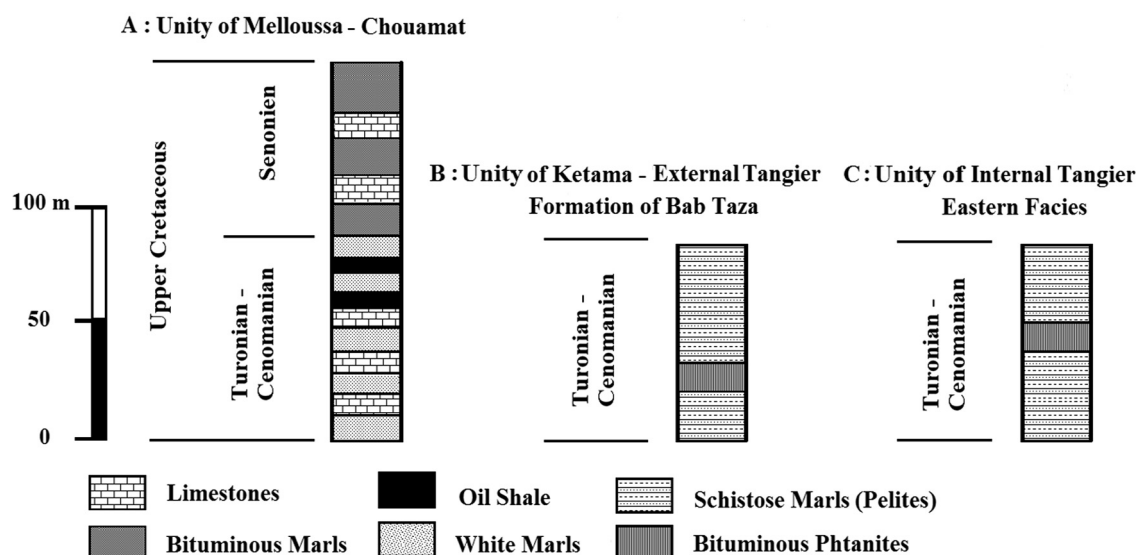


Figure 2 Stratigraphic columns of the Flyschs nappes and External Rif (Marocain Rif) showing the sample position investigated (A: Durand-Delga and Olivier, 1988) (B, C: Durand-Delga and Kornprost, 1985; Kornprost et al., 1980).

5 °C ms⁻¹ and maintained at 650 °C for 10 s. Thermochemolysis products were carried into GC–MS by He gas.

GC/MS separation was performed on a Focus GC coupled with a DSQ II quadrupole using a BPX (SGE) capillary column (30 m long, 0.25 mm i.d.). Column temperature was programed from 60 to 300 °C at a rate of 5 °C min⁻¹ and held for 30 min at 300 °C. Ionization was performed in electron impact (70 eV). The compounds were identified on the basis of their GC retention times and by comparisons of their mass spectra with those of standards and with data from the literature.

2.4. Bitumen extraction

The bituminous rock samples (<180 µm) were Soxhlet-extracted for 48 h with a dichloromethane/methanol (2:1 volume ratio) mixture. The solution was then filtered and the solvent was evaporated under reduced pressure using a rotary evaporator. The yields of total organic extracts (bitumens) are presented in Table 2.

2.5. Fractionation

The lipid extracts were fractionated on a silica-potassium hydroxide column by the method of McCarthy and Duthie (1962). After tests on TLC (Merck Kiesel gel 60F254, thickness of the silica layer is 0.2 mm, supported by a 2–3 cm layer of alumina), different fractions were collected into three fractions: neutral, acid, and polar fractions (Table 2).

2.6. Analysis of bitumens

The aliphatic hydrocarbon fractions were analyzed using gas chromatography (GC-FID) and gas chromatography/mass spectrometry (GC/MS). The analysis conditions were kept the same as mentioned above.

3. Results and discussion

3.1. Rock–Eval analysis

The total organic carbon (TOC) and Rock–Eval parameters for the bituminous rock samples are displayed in Table 3. TOC ranges between 0.45% and 4.47 %, whereas the HI and $T_{\max}$ values vary between 37 and 282 mg hydrocarbons (HC)/g TOC and 439–465 °C, respectively (Table 3) (Groune et al., 2013). According to Peters and Cassa (1994), the typical HI/ $T_{\max}$ diagram (Fig. 3) reveals the Upper Cretaceous bituminous rock sample plot in the Types II, III and IV kerogen region for AA, TA and TE, BT successively. The weak positive correlation between S_1 and S_2 for the studied samples (AA, TA and TE, BT on the one hand) (Fig. 4), suggests that the organic matter of this formation was derived from a different origin, thus supporting the data presented in Fig. 3. The $T_{\max}$ value for AA sample from the oil shale indicates that it is of early–intermediate mature oil formation stage (Table 3, Fig. 3), whereas $T_{\max}$ values of the other TA, TE and BT samples are not significant due to their low S_2 hydrocarbon value (<2.5 mg HC/g rock) (Table 3) (Groune et al., 2013).

Table 2 Yields of the total extracts and fractions of bituminous rock samples.

Sample	Total extract (%) of rock	Total extract of rock (ppm) (mg _{lip} /Kg _{rock})	% Yield fraction/total extract		
			Neutral	Acid	Polar
TA	0.307436	3074.36	3.86	0.32	95.82
TE	0.798709	7987.09	23	0.74	76.26
BT	0.936468	9364.68	51.35	3.45	45.20
AA	0.589710	5897.10	74.19	1.19	24.62

Table 3 Rock–Eval parameters of bituminous rock samples.

Sample	Parameter				
	TOC (%)	$T_{\max}$ (°C)	HI (mgHC/gTOC)	S_1 (mg/g)	S_2 (mg/g)
TA	0.45	439	100	0.04	0.45
TE	4.44	465	37	0.1	1.63
BT	4.47	461	53	0.49	2.38
AA	4.3	440	282	0.96	12.14

TOC, Total Organic Carbon, Wt%; S_1 , volatile hydrocarbon (HC) content, mg HC/g rock; S_2 , remaining HC generative potential, mg HC/g rock; HI, Hydrogen Index: $S_2 \times 100/\text{TOC}$, mg HC/g TOC; $T_{\max}$, temperature at which the maximum amount of organic S_2 hydrocarbons.

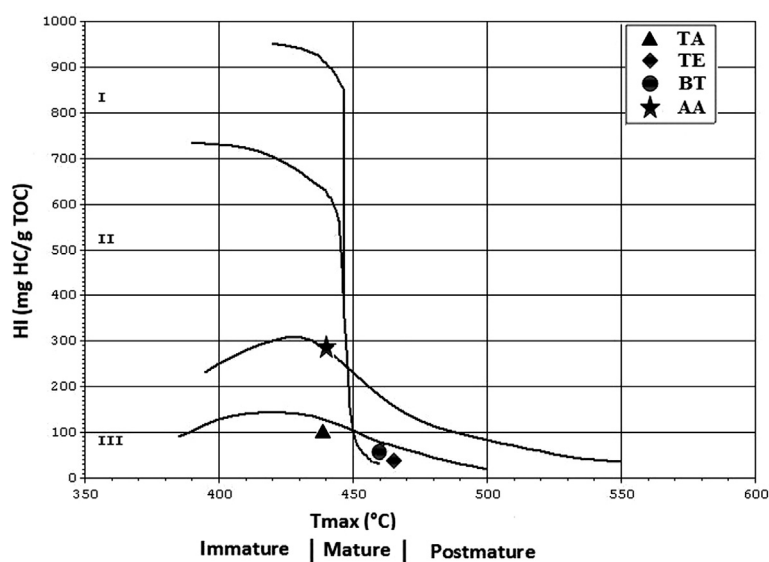


Figure 3 Plot of Hydrogen Index (HI) versus (Rock–Eval) $T_{\max}$ values for the samples analyzed showing kerogen quality and thermal maturity stages (diagram from Espitalié et al., 1986).

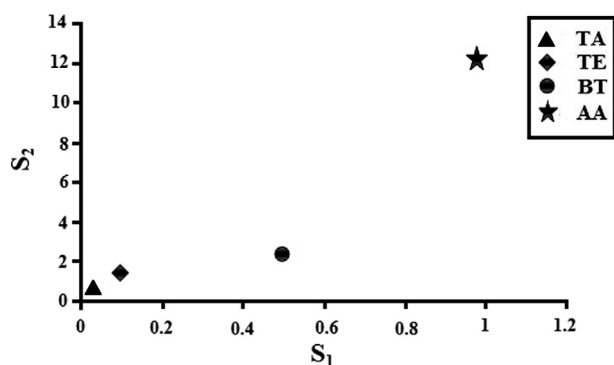


Figure 4 A plot of S_1 vs. S_2 showing a weak positive correlation between S_1 and S_2 .

3.2. Flash pyrolysis (Py–GC/MS)

The pyrolysis products of the 4 rock samples (Fig. 5) are mainly aliphatic hydrocarbons identified in the C_{12} – C_{33} range. It is interesting to notice that the distributions are exactly the same as that observed using the protocol of extraction and

fractionation. This presence of hydrocarbon compounds is very important in AA sample followed by BT sample, then TE, and TA samples.

3.3. Fractionation yields

The results of the bituminous fractionation of the rock samples are shown in Table 2. The TA and TE samples were characterized by the highest amount of polar fraction yields compared to the acid and neutral fractions. The neutral fraction yield is higher in the TE sample than in the TA one. The BT and AA samples were characterized by the upper amount of neutral fraction yields followed by polar fraction yields and the lowest amount of acid fraction yields.

3.4. Chromatographic analysis of the lipids

3.4.1. *n*-Alkanes

The distribution of the aliphatic hydrocarbons from the neutral fractions is given in Fig. 7. Based on ion extraction, mass of m/z 85, *n*-alkanes were detected in the C_{12} – C_{33} range. The more abundant *n*-alkanes are C_{16} and C_{18} for BT, C_{18} and C_{24} for TA, C_{19} and C_{20} for AA, C_{16} for TE samples. The distribution of *n*-alkanes can be used as an indicator; although,

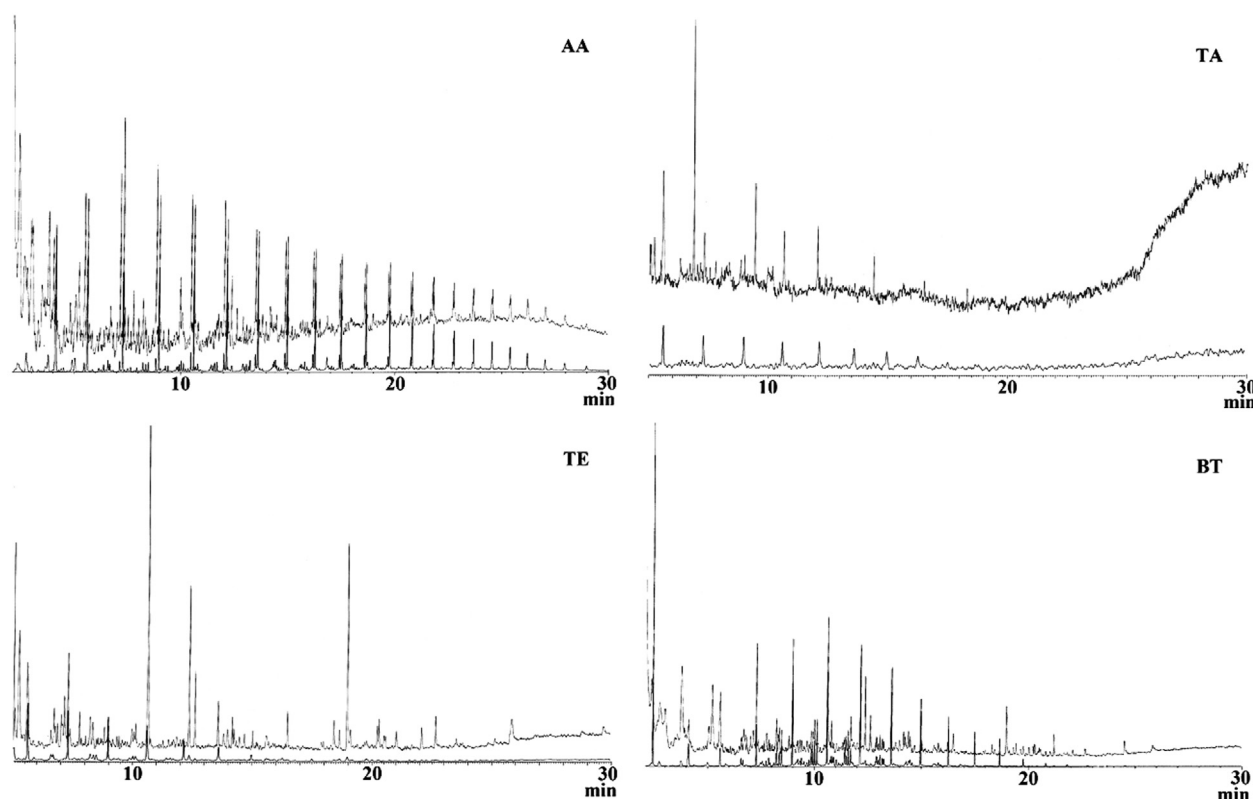


Figure 5 Chromatograms obtained after Py-GC/MS analysis of the bituminous rock samples.

Table 4 Biomarker parameter for extracts of bituminous rock samples studied.

Sample	<i>n</i> -Alkanes				Steranes					Hopane (Terpane)		
	C_{max}	CPI_{24-34}^a	Pr/Ph	Waxiness	C_{27} (%)	C_{28} (%)	C_{29} (%)	$C_{29} 20S / (20S + 20R)$	$C_{29}\beta\beta / (\beta\beta + \alpha\alpha)$	Ts/Tm ^b	Ts / (Ts + Tm)	C_{29}/C_{30}
TA	nC_{24}	1,02	1,03	1,83	26,74	25,24	48,02	0,39	0,86	0,66	0,39	0,93
TE	nC_{16}	0,94	0,60	0,66								
BT	nC_{18}	1,06	1,07	0,79								
AA	nC_{19}	1,01	0,41	1,12	64,07	12,39	23,59	0,34	0,76	1,17	0,54	0,75

^a After Bray and Evans (1961); Waxiness: $\Sigma (n-C_{21}-n-C_{31}) / \Sigma (n-C_{15}-C_{20})$; Pr/Ph: pristane/phytane.

^b Ts/Tm: trisnorhopanes/trisnorhopanes ratios.

not a very specific one, for organic source of oils (Duan and Ma, 2001). Indeed, the abundant distribution of higher molecular weight alkanes ($\geq C_{20}$) with odd-predominance is characteristic of an organic matter with a plant origin (Kolattudy, 1970; Powell and McKirdy, 1973; Tissot et al., 1977; Tulloch, 1976), whereas the abundant distribution of low molecular weight alkanes ($< C_{20}$) with slight odd-predominance indicates an algal/bacterial origin (Gelipi et al., 1970; Weete, 1976; Tissot and Welte, 1984; Peters and Moldowan, 1993). The chromatograms of the studied samples (Fig. 7) showed a marked predominance of short to long chain *n*-alkanes, which is an indication of organic matter from a marine environment for AA and TE samples while the organic matter of TA and BT samples originates from land or mixed environment (Tissot and Welte, 1978; Ebukanson and Kinghorn, 1986; Murray and Boreham, 1992), which is supported by the results of the Rock-Eval pyrolysis (Fig. 3).

The plot in Fig. 8 allows a better comparison of the distribution of *n*-alkane and *n*-alk-1-ene that was different for the various samples, having some characteristics that deserve attention. The AA, TE and TA samples showed a distribution of *n*-alkane/*n*-alk-1-ene doublets with an even dominance of carbon numbers, whereas the BT sample showed a distribution of *n*-alkane and *n*-alk-1-ene with dominant odd carbon numbers.

3.4.2. Acyclic isoprenoids

Pristane (Pr) and phytane (Ph) are isoprenoid alkanes with 19 and 20 carbon atoms, respectively. The pristane to phytane ratio (Pr/Ph) is an indicator of depositional environment and source of organic matter (Maxwell et al., 1972, 1973; Didyk et al., 1978; Brooks and Smith, 1969; Powell and Makriday, 1973; Chandra et al., 1994; Large and Gize, 1996). These early workers assumed that both pristane and phytane were derived

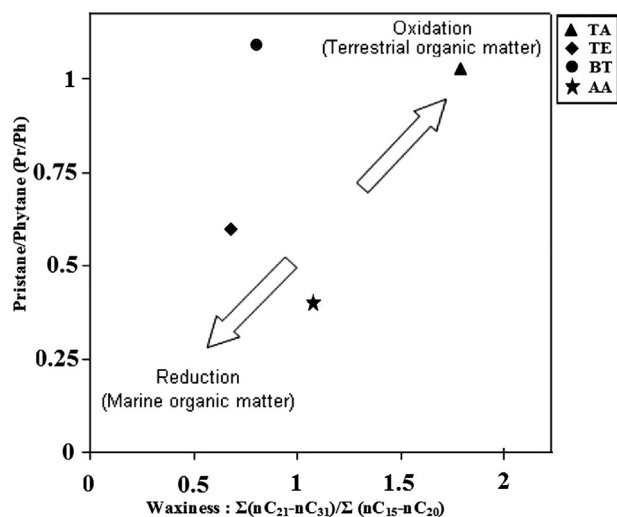


Figure 6 Cross plots of Pr/Ph versus waxiness $\Sigma (nC_{21}-nC_{31})/\Sigma (nC_{15}-nC_{20})$ for the studied samples.

from the phytol side chain of chlorophyll. More recently, it has been shown that pristane can be derived from α -tocopherol and phytane from the bis-phytanyl ethers which occur in archaeobacteria (Philp, 1994). According to Cooper (1990), pristane and phytane are derived from the chlorophyll of higher plants, algae and photosynthetic bacteria and from archaeobacteria. A Pr/Ph ratio > 3.0 indicates oxidizing conditions, low values of Pr/Ph ratio (< 0.8) indicate algae/bacteria origin (anoxic conditions), and values between 0.8 and 3.0

suggest intermediate conditions (suboxic conditions) (Ten Haven et al., 1987; Amann and Hideki, 1997; Sarmiento and Rangel, 2004; Basent et al., 2005). The existence of various precursors therefore indicates that the Pr/Ph ratio should be used with care. For our samples (Table 4), the Pr/Ph ratios are < 0.6 for AA sample and 0.60 for TE sample, indicating that these samples derived from source rocks deposited under anoxic conditions, whereas the Pr/Ph ratios for the other samples TA and BT are 1.03 and 1.07 indicating that these samples derived from source rocks deposited under suboxic conditions. The degree of waxiness ($\Sigma (nC_{21}-nC_{31})/\Sigma (nC_{15}-nC_{20})$ ratio) (Table 4) that was used as an environmental source parameter (Connan and Cassou, 1980) and the relationship with the Pr/Ph ratio (Fig. 6) confirm that AA and TE samples originate from marine organic matter; whereas, TA and BT samples are derived from terrestrial or mixed organic matter.

3.4.3. Carbon Preference Index (CPI)

The CPI value is a parameter that is influenced by maturity and by the type of organic matter (Tissot and Welte, 1984). The CPI indices initially introduced by Bray and Evans (1961) are the most used, there is no harmonization between the authors on how to perform intercourse. The odd carbon preference is characteristic of oils derived from source rocks deposited in non-marine depositional environments (Moldowan et al., 1985). In contrast, Palacas et al. (1984) concluded that an even numbered *n*-alkane preference is commonly observed in bitumens and oils derived from carbonate or evaporate rocks. In these studied samples, the CPI values calculated in the range $nC_{24}-nC_{34}$ (after Bray and Evans,

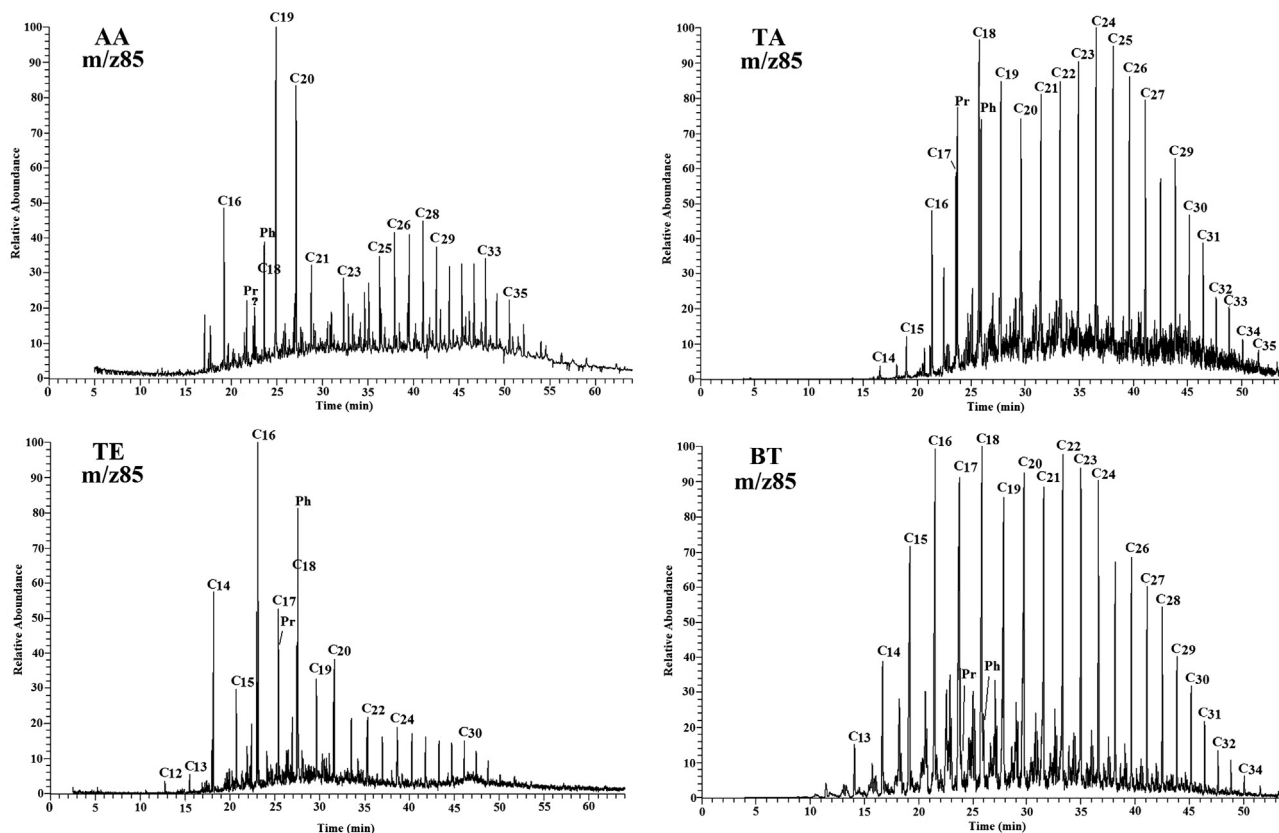


Figure 7 Chromatograms of the saturated hydrocarbon fractions of the bituminous rock samples.

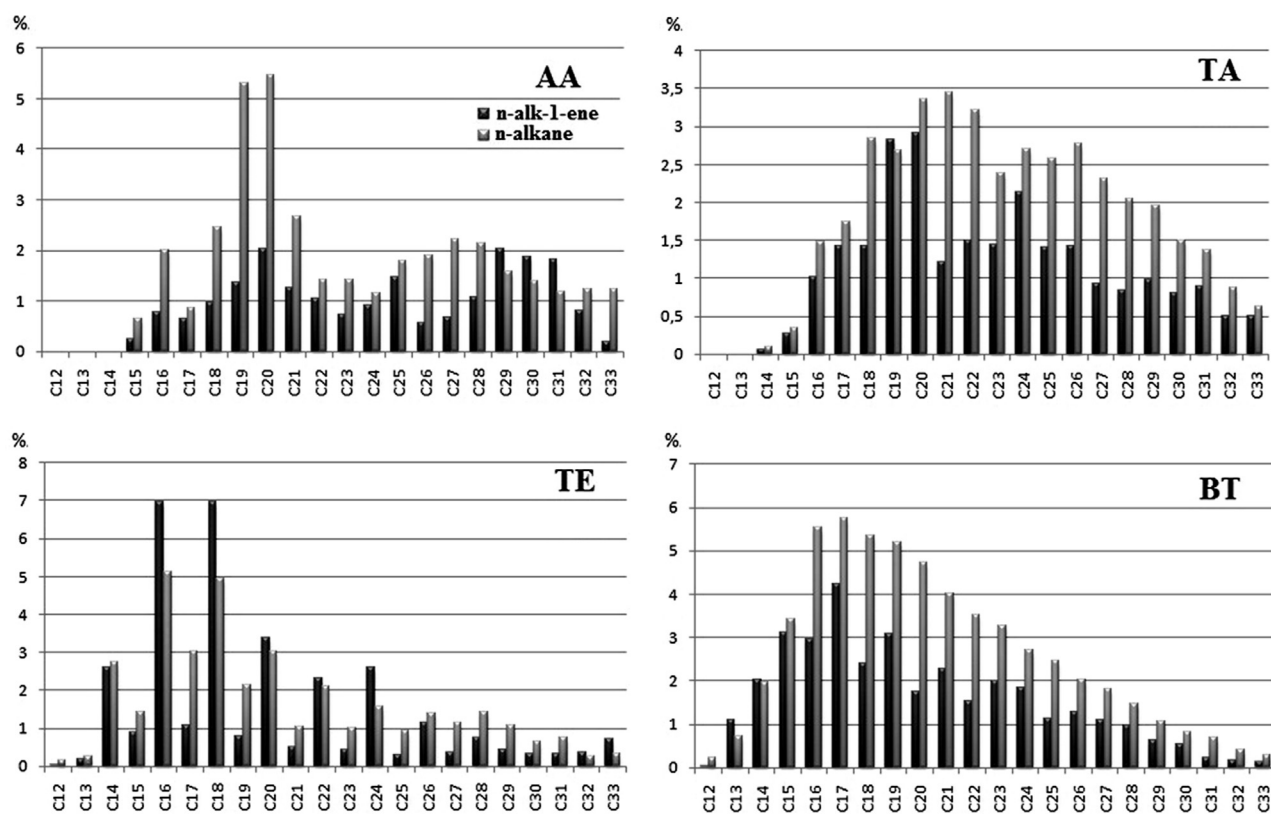


Figure 8 Relative abundance of *n*-alkane and *n*-alk-1-ene in the bituminous rock samples.

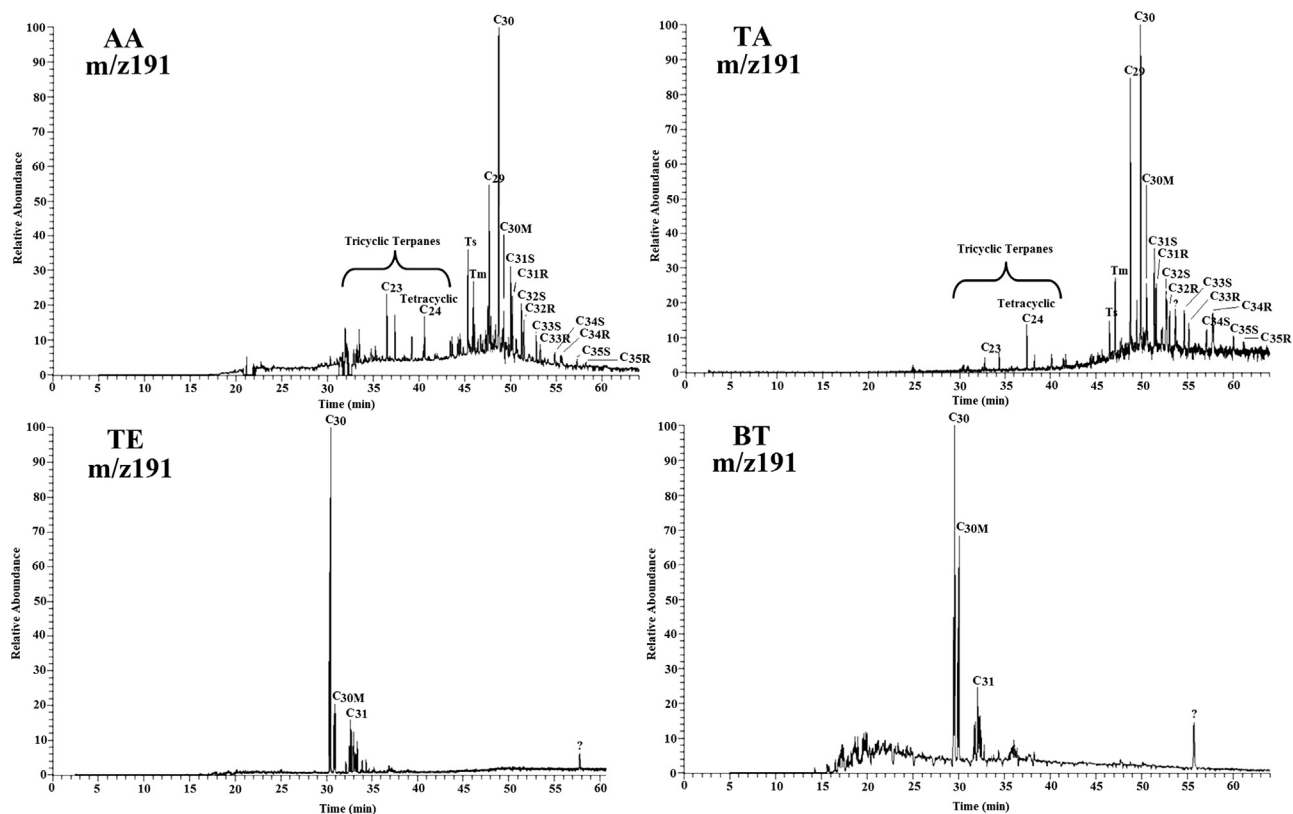


Figure 9 m/z 191 mass-chromatograms of saturated hydrocarbons of bituminous rock samples studied.

Table 5 Peak assignments for alkane hydrocarbons m/z 191 mass chromatograms (Hopane) and m/z 217 mass chromatograms (sterane, diasterane).

Peak	Compound
Ts	18 α (H),22,29,30-trisnorhopane
Tm	17 α (H),22,29,30-trisnorhopane
C29	17 α ,21 β (H)-nor-hopane
C30	17 α ,21 β (H)-hopane
C30M	17 β ,21 α (H)-moretane
C31S	17 α ,21 β (H)-homohopane (22S)
C31R	17 α ,21 β (H)-homohopane (22R)
C32S	17 α ,21 β (H)-homohopane (22S)
C32R	17 α ,21 β (H)-homohopane (22R)
C33S	17 α ,21 β (H)-homohopane (22S)
C33R	17 α ,21 β (H)-homohopane (22R)
C34S	17 α ,21 β (H)-homohopane (22S)
C34R	17 α ,21 β (H)-homohopane (22R)
C35S	17 α ,21 β (H)-homohopane (22S)
C35R	17 α ,21 β (H)-homohopane (22R)
dC(no) $\beta\alpha$ S	13 β ,17 α (H)-diasteranes (20S)
dC(no) $\beta\alpha$ R	13 β ,17 α (H)-diasteranes (20R)
dC(no) $\alpha\beta$ S	13 α ,17 β (H)-diasteranes (20S)
dC(no) $\alpha\beta$ R	13 α ,17 β (H)-diasteranes (20R)
C(no) $\alpha\alpha$ S	5 α ,14 α (H),17 α (H)-steranes (20S)
C(no) $\alpha\beta\beta$ R	5 α ,14 β (H),17 β (H)-steranes (20R)
C(no) $\alpha\beta\beta$ S	5 α ,14 β (H),17 β (H)-steranes (20S)
C(no) $\alpha\alpha$ R	5 α ,14 α (H),17 α (H)-steranes (20R)

No: number of carbon.

1961) are 1.02, 0.94, 1.06, and 1.01 for TA, TE, BT and AA samples, respectively (Table 4), showing neither even nor odd carbon preference, as an indication of mature samples (Tissot and Welte, 1984).

3.4.4. Terpenic biomarkers

Terpenes are formed by the union of isoprenoid units, the steranes are the most important petroleum hydrocarbons that retain the characteristic structure of the original biological compounds. Tricyclic and tetracyclic hopanes as well as other compounds contribute to the terpene fingerprint (mass chromatogram m/z 191) commonly used to relate oils and source rocks (Seifert and Moldowan, 1979; Hunt, 1996; Peters et al., 2005). The terpene biomarkers present in the saturated hydrocarbon fraction of the studied samples were detected using the characteristic ion extract $m/z = 191$. Fragmentograms are not similar for both TA and AA samples, contrary to the two other samples (Fig. 9). The assignment of the peaks labeled in Fig. 9 is listed in Table 5. The principal distinct features are tricyclic terpanes, Ts/Tm, Ts/(Ts + Tm) and C_{29}/C_{30} hopane ratios.

Tricyclic terpanes are members of a useful series of biomarkers for differentiating different types of organic matter and depositional environments (Seifert and Moldowan, 1979; Walples and Machihara, 1991; Andrew et al., 2001; Peters et al., 2005). AA sample has relatively high abundance of the C_{23} tricyclic terpene and low abundance than the C_{24} tetracyclic one (Fig. 9), which supports the high contribution from marine material of the source rocks. On the Contrary, the TA sample has high abundance of the C_{24} tetracyclic and low abundance than the C_{23} tricyclic (Fig. 9) which supports the high contribution from terrestrial material to the source

rocks (Zumberge, 1987; Burwood et al., 1992; Hanson et al., 2000). In the other samples, the presence of tricyclic terpanes does not seem obvious (Fig. 9).

The Ts/Tm ratio is 0.66 for TA sample and 1.17 for AA sample (Table 4), indicating that the 18 α (H)-trisnorhopane (Tm) is dominant over its counterpart 17 α (H)-trisnorhopanes (Ts) in TA sample, contrary to AA sample. The trisnorhopanes (Ts) and trisnorhopanes (Tm) seem either absent or are present in very minor amounts in the other samples (TE, BT) (Fig. 9). Ts/(Ts + Tm) ratio is one of the indices that has been used for characterization of the source oil (Wang et al., 1998) and evaluation of the thermal maturity (Peters et al., 2005). Higher values indicate higher maturities (Waseda and Nishita, 1998; Seifert and Michael Moldowan, 1978). Ts/(Ts + Tm) values are 0.39, 0.54 for TA and AA samples, respectively (Table 4), suggesting that these sediments are thermally mature.

The studied samples have higher concentrations of C_{30} than C_{29} hopane. The C_{29}/C_{30} 17 α (H) hopane ratio values are 0.93, 0.75, and 0.57 for TA, AA, and TE samples, respectively (Table 4). The ratio cannot be determined for the BT sample. According to the C_{29}/C_{30} 17 α (H) hopane ratios values (Connan et al., 1986), it seems that the TA sample is more rich in carbonaceous organic matter than the AA and TE samples.

3.4.5. Sterane biomarkers

The transformation of sterols into diagenetic steranes (Mackenzie et al., 1982) is a complex process, yielding the isomers 5 α (H) and 5 β (H), 14 α (H) and 14 β (H) (Seifert and Moldowan, 1979; Mackenzie et al., 1980) the number of carbon atoms being preserved. The distribution of steranes as those of sterols (Huang and Meinschein, 1979) can be used as an indicator of organic input and maturity (Mackenzie and McKenzie, 1983). The different proportions of $C_{27}:C_{28}:C_{29}$ regular steranes have been proposed as indicative of organic input and maturity (Moldowan et al., 1985; Philp et al., 1991). An abundance of C_{29} over C_{27} steranes would suggest a terrestrial source, whereas C_{27} steranes predominating over C_{29} steranes would indicate mainly a marine or aquatic source (Lijmbach, 1975; Huang and Meinschein, 1979; Palacas et al., 1984; Gonzalez-Vila, 1995; Hunt, 1995; Peters et al., 2005). The characteristic m/z 217 mass fragmentograms corresponding to the steranes and diasteranes of the representative samples are shown in Fig. 10 and the corresponding chemical structures are given in Table 5. The compounds were identified according to previously reported mass spectra and relative retention times. The AA sample is characterized by the dominance of the C_{27} sterane (20R, Fig. 10) on the C_{29} sterane (20R, Fig. 10) (Table 4), which suggests an origin from marine organic matter. The TA sample is characterized by dominance of the C_{29} sterane (20R, Fig. 10) on the C_{27} sterane (20R, Fig. 10, Table 4), which indicates an origin from terrestrial organic matter. The steranes diagram (Fig. 11) confirms these assumptions. In addition, the ratio 20S/(20S + 20R) for regular C_{29} steranes and the $\beta\beta(\beta\beta + \alpha\alpha)$ ratio for C_{29} are 0.34, 0.76, respectively in AA sample, and 0.39 and 0.86, respectively, in TA samples (Table 4) suggesting that these sediments are thermally mature (Moldowan et al., 1994). A higher degree of maturity and a more pronounced terrigenous source (Petersen et al., 2000; Andrew et al., 2001) is observed for the TA sample compared to the AA sample.

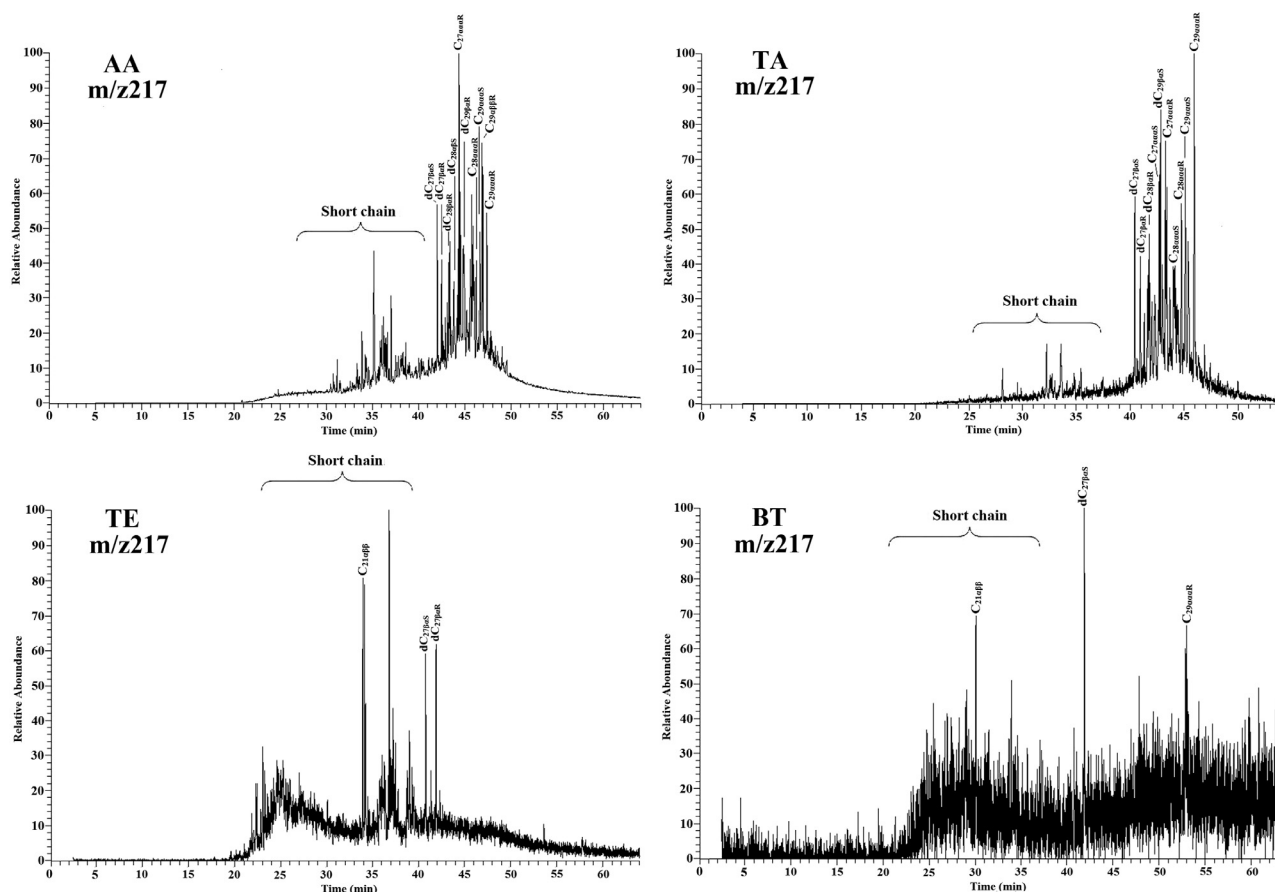


Figure 10 m/z 217 mass-chromatograms of saturated hydrocarbons of bituminous rock samples studied.

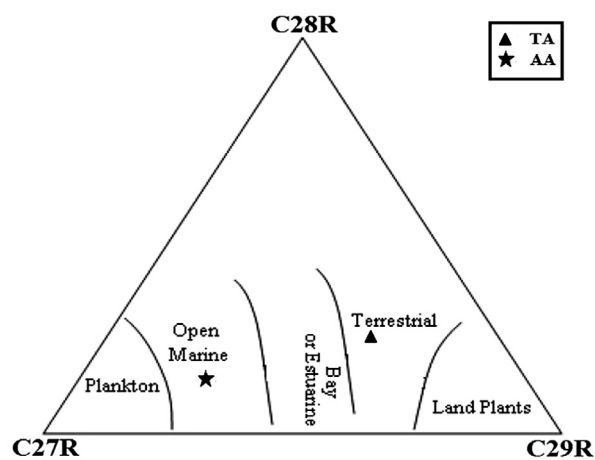


Figure 11 Ternary diagram showing C27–C28–C29 $\alpha\alpha\alpha$ R regular steranes of bituminous rock samples studied.

4. Conclusions

The chromatography study of the Upper Cretaceous bituminous rocks in the Moroccan Rif gives important information about the characterization and classification of organic matter present in these sediments. Using geochemical biomarker parameters related to thermal maturity, organic matter source,

age and depositional environment, the present chromatographic study showed that:

- (i) The samples are generally thermally mature, depending on the geochemical biomarker parameters.
- (ii) The AA sample (oil shale) from Arba Ayach site is rich in aliphatic compounds, derived of organic matter from marine, and it has the qualities of a good source rock.
- (iii) The TA sample (bituminous marl) from Tangier site is rich in polar compounds, derived of organic matter from terrestrial.
- (iv) The TE, BT samples (bituminous phthanite) from Tetouan, Bab Taza sites successively contain aliphatic and polar compounds, but these sediments (bituminous phthanites) are not potential source rocks for hydrocarbons.

This is confirmed by the Rock–Eval pyrolysis results by suggesting Type II, III kerogen for AA, TA samples respectively, and Type IV kerogen for TE, BT samples. Type IV kerogen is poor in hydrogen, therefore inert to generate hydrocarbons (Peters and Cassa, 1994). Additional Rock–Eval pyrolysis results confirmed the thermal maturity for the AA sample. Although, it is contrary for the other samples due to their low S_2 hydrocarbon value (<2.5 mg HC/g rock) (Groune et al., 2013).

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